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[TITLE OF THE INVENTION] ILLUMINATION DEVICE, EXPOSURE APPARATUS PROVIDED WITH THE ILLUMINATION DEVICE, AND METHOD OF FABRICATING SEMICONDUCTOR DEVICE USING THE EXPOSURE APPARATUS
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[Title of the Invention] ILLUMINATION DEVICE, EXPOSURE APPARATUS PROVIDED WITH THE ILLUMINATION DEVICE, AND METHOD OF FABRICATING SEMICONDUCTOR DEVICE USING THE EXPOSURE APPARATUS

[Scope of the Claims]

[Claim 1]

An illumination device, comprising:

light source means which provides a light beam, a multi-light source formation optical system which forms many light sources based on the light beam from the light source means, and a condenser optical system which condenses the light beam from the many light sources formed by the multi-light source formation optical system and illuminates an illuminated surface;

the multi-light source formation optical system having a first optical element group including many first optical elements; and

the many first optical elements respectively having a first optical surface having an arc-shaped contour in order to form the many light sources by dividing the light beam from the light source means into many arc-shaped light beams in a manner of wavefront dividing.

[Claim 2]

The illumination device as set forth in claim 1,

wherein optical surfaces of the many first optical elements are respectively formed in a predetermined first reflecting curved surface.

[Claim 3]

The illumination device as set forth in claim 2,

wherein the first optical element is constituted by an eccentric mirror having an optical axis outside an effective region of the first reflecting curved surface.

[Claim 4]

The illumination device as set forth in claim 2 or 3, comprising:

the multi-light source formation optical system further having a second optical element group including many second optical elements;

the many second optical elements respectively having a second optical surface which is formed in a rectangular shape; and

the second optical surface of the many second optical elements being respectively formed in a predetermined second reflecting curved surface.

[Claim 5]

The illumination device as set forth in claim 4, comprising:

the second optical element having an optical axis at a center position of the second optical element.

[Claim 6]

The illumination device as set forth in any one of claims 2-5,

wherein the condenser optical system is constituted only by one or more reflecting type optical elements.

[Claim 7]

The illumination device as set forth in claims 1-6, comprising:

the first optical element group having a plurality of first optical element columns, in which a plurality of the first optical elements are arranged along a predetermined first direction, the columns arranged along a second direction perpendicular to the predetermined first direction, and

the many first optical elements which structure the optical element columns form a light source image which is arranged nonlinearly.

[Claim 8]

The illumination device as set forth in claim 7,

wherein an arbitrary first optical element within the many first optical elements which structure the first optical element column are inclined and arranged with respect to a predetermined plane in which the many first optical elements are arranged so that a direction of the first reflecting curved surface is different.

[Claim 9]

The illumination device as set forth in any of claims 1-8, wherein the below condition is satisfied:

$0.01 < | f_F / f_c | < 0.5$

where f_F is a focal length of the first optical element structuring the first optical element group, and f_c is a focal length of the condenser optical system.

[Claim 10]

An illumination device, comprising:

light source means which provides a light beam, a multi-light source formation optical system which forms many light sources based on the light beam from the light source means, to uniformly illuminate an illuminated surface;

the multi-light source formation optical system having a first optical element group including many first optical elements to form the many light sources, and a second optical element group having many second optical elements that illuminate the illuminated surface by condensing the light beam from the many light sources formed by the first optical element group;

the many first optical elements respectively having a first optical surface having an arc-shaped contour in order to form the many light sources by dividing the light beam from the light source means into many arc-shaped light beams in a manner of wavefront dividing; and

the many second optical elements respectively having second optical surfaces formed in a rectangular shape.

[Claim 11]

The illumination device as set forth in claim 10, wherein the second optical surface of the many second optical elements are respectively formed in a predetermined second reflecting curved surface, and

the predetermined second reflecting curved surface is arranged along a standard curved surface of the second optical element group.

[Claim 12]

The illumination device as set forth in any one of claims 1-11, wherein an auxiliary multi-light source formation optical system is positioned in an optical path between the light source means and the multi-light source formation optical system; and

the auxiliary multi-light source formation optical system has a first auxiliary optical element group including many first auxiliary optical elements.

[Claim 13]

The illumination device as set forth in claims 1 to 12, wherein a changing means for changing a shape and a size of a surface light source composed by the many light sources formed by the multi-light source formation optical system is positioned in an optical system between the light source means and the illuminated surface.

[Claim 14]

An exposure apparatus, comprising:

an illumination device as set forth in any one of claims 1-13,

a mask stage which can hold a mask arranged at the illuminated surface to be illuminated by the illumination device,

a wafer stage which can hold a photosensitive substrate,

a projection optical system which projects a predetermined pattern formed in the mask onto the photosensitive substrate; and

a driving device which relatively moves the mask stage and the wafer stage with respect to the projection optical system when a predetermined pattern formed in the mask is projected onto the photosensitive substrate.

[Claim 15]

A method of fabricating a semiconductor device, using the exposure apparatus as set forth in claim 14, including:

a step of exposing a pattern of the mask onto the photosensitive substrate via the projection system.

[Detailed Description of the Invention]

[0001]

[Industrial Use of the Invention]

This invention relates to an illumination device which uniformly illuminates an illuminated surface, and more particularly to a desired illumination device and an exposure apparatus used when a semiconductor device is fabricated by a photolithography process. Furthermore, this invention relates to a method of fabricating a desired semiconductor device using the exposure apparatus.

[0002]

[Prior Art]

Conventionally, with respect to an exposure apparatus for fabricating a semiconductor device provided with an illumination device, a circuit pattern formed on a mask is projectingly transferred onto a photosensitive substrate, such as a coated wafer, via a projection optical system. This projection optical system has two reflecting mirrors formed of a concave surface mirror and a convex surface mirror. Only a good image portion of an arc-shaped region outside an axis of the projection optical system is used, and only an arc-shaped region on a mask is projectingly transferred onto a wafer. Furthermore, transferring of a circuit pattern of the entire mask can be performed by scanning a mask and a wafer in a predetermined direction.

[0003]

According to this scanning type exposure, there is an advantage that high resolution can be obtained with relatively high throughput.

In this type of exposure apparatus, an illumination device is desired which can uniformly illuminate the entire arc-shaped region on a mask with a predetermined numerical aperture (NA). For example, Japanese Laid-Open Patent Application 60-232552 discloses an illumination device which can uniformly illuminate a region on a mask in an arc manner.

[0004]

In the illumination device which is disclosed in Japanese Laid-Open Patent Application 60-232552, as shown in Fig. 16(a), a light beam from a super high pressure mercury-arc lamp 21 is condensed onto an incident surface of an optical integrator 23 by an elliptic mirror 22. Furthermore, as shown in Fig. 16(b), this optical integrator 23 is constituted by combining two cylindrical lens assemblies (23a, 23d) having a focal length f_1 and two cylindrical lens assemblies (23b, 23c) having a focal length f_2. A light beam having different numerical apertures in perpendicular directions is formed by this structure. A light beam through the optical integrator 23 is condensed by a condenser lens 24. As shown in Fig. 16(c), a slit plate 25 having an arc-shaped aperture portion 25a is illuminated, and then, a mask which is an illuminated surface is uniformly illuminated via a condensing optical system 26.

[0005]

[Problem to be Solved by the Invention]

However, in the illumination device disclosed in the above-mentioned Japanese Laid-Open Patent Application 60-232552, as shown in Fig. 16(c), a rectangular-shaped region BF is illuminated so as to irradiate the arc-shaped aperture portion 25a on the slit plate, so only a small part of the light beam can be effectively used as arc illumination.

[0006]

In general, an arc-shaped cord length is set to be as long as possible so as to enlarge an exposure region, and an arc-shaped slit width 25b is set to be relatively narrow so as to be restricted to a good image region of a mirror projection optical system which projects a mask onto a wafer. Therefore, illumination effectiveness is determined by an area ratio between the rectangular-shaped region BF and the arc-shaped aperture portion 25a. In a conventional illumination device shown in Figs. 16(a), (b), and (c), there is a fatal disadvantage that a light amount loss is significant in principle. Because of this result, a sufficient light amount cannot be obtained on an irradiating surface (mask or wafer), so scanning speed between a mask and

a wafer cannot be accelerated. Therefore, there was a problem that this cannot obtain a high throughput.

[0007]

Accordingly, in this invention, a main object of this invention is to provide an illumination device, solving the above-mentioned problem, in which illumination effectiveness is much better than a conventional device and can sufficiently obtain a high throughput, and uniform illumination such as Koehler illumination can be accomplished, an exposure apparatus provided with the illumination device, and a method of fabricating a desired semiconductor device using the exposure apparatus.

[0008]

Furthermore, recently, by using a light source device, such as a synchrotron generation device or the like, which provides a soft X ray, an exposure apparatus for the next generation which can project and expose a further micro line width pattern onto a photosensitive substrate is demanded. An illumination device and an exposure apparatus have not been proposed which can uniformly illuminate X ray such as soft X ray or the like onto a mask.

Because of this, in this invention, a secondary object of this invention is to provide an illumination device and an exposure apparatus which can effectively uniformly illuminate X ray onto a mask and a method of fabricating a desired semiconductor device by X ray.

[0009]

[Means of Solving the Problem]

In order to accomplish the above-mentioned main object, in the invention related to claim 1, for example, as shown in Figs. 1 and 8, the light source image formation optical system 2 has a first optical element group (2a, 20a) including many first optical elements (E, E_1), and

the many first optical elements (E, E_1) respectively have first optical surfaces (RS, RS_1) having an arc-shape contour in order to form many light sources by dividing the light beam from a light source means into many arc-shaped light beams in a manner of wavefront dividing.

[0010]

Because of this, the light which has been wavefront-divided into an arc shape by the light source image formation optical system 2 and transmitted to the respective first optical surfaces (RS, RS_1) of the many first optical elements (E, E_1) forms an arc-shaped illumination region and are superimposed on a mask 5 or a wafer 7 or the like as an illuminated surface by

a condensing operation (or "action") of a condenser optical system 3. Therefore, uniform illumination can be effectively realized.

[0011]

Furthermore, in the invention related to claim 2, the optical surfaces (RS, RS_1) of the many first optical elements (E, E_1) are respectively formed in a predetermined first reflecting curved surface. In this case, as described in claim 3, it is preferable that the first optical elements (E, E_1) are constituted by an eccentric mirror having optical axes (Ax_E, Ax_{E1}) outside an effective region of the first reflecting curved surface.

[0012]

Furthermore, in the invention related to claim 4, the multi-light source formation optical system 2 further has a second optical element group 20b including many second optical elements E_2. The many second optical elements E_2 respectively have a rectangular-shaped second optical surface RS_2. The second optical surface RS_2 of the many second optical elements E_2 can be respectively formed in a predetermined second reflecting curved surface. By so doing, even if the light having an angle of divergence is provided from a light source means 1, a light beam supplied via the first optical element group 20a is again condensed in the second optical element group 20b effectively, the mask 5, the wafer 7, or the like as an illuminated surface can be effectively illuminated in an arc shape.

[0013]

In this case, like the invention described in claim 5, it is preferable that the second optical element E_2 has an optical axis Ax_{E2} at a center position C_{E2} of the second optical element.

In the invention related to claim 6, the condenser optical system 3 is constituted only by one or more reflecting type optical elements. Because of this, the multi-light source formation optical system 2 and the condenser optical system 3 are constituted only by a reflecting system, so even when an X-ray generation device, such as a synchrotron generation device or the like, which provides X-rays with a wavelength of 20 nm or less is a light source means, a mask 5 or the wafer 7 or the like as an illuminated surface can be uniformly effectively illuminated in an arc shape.

[0014]

In the invention as set forth in claim 7, the first optical element group 20a has a plurality of the first optical element columns, in which many first optical elements E_1 are

arranged along a predetermined first direction, the columns being arranged along a second direction perpendicular to the predetermined first direction, and

many first optical elements E_1 which structure the optical element columns are constituted so as to form a light source image arranged nonlinearly. By so doing, for example, a light source image I is formed so as to inscribe the respective second optical elements E_2 of the second optical element group 20b, so a light amount loss of a light beam going through the respective second optical elements E_2 can be controlled to a minimum.

[0015]

In this case, as set forth in claim 8, it is preferable that an arbitrary first optical element E_1 with many first optical elements E_1 which structure the first optical element columns are inclined and arranged with respect to a predetermined plane P_a in which the many first optical elements E_1 are arranged so that the direction of the first reflecting curved surface is different.

In the invention as set forth in claim 9, where f_F is a focal length of the first optical element structuring the first optical element group, and fc is a focal length of the condenser optical system, the below condition is satisfied:

[0016]

$0.01 < | f_F / f_c | < 0.5$

As a result, an arc-shaped illumination region that is uniform on the illuminated surface can be formed, while attempting to make the device compact.

In addition, in the invention as set forth in claim 10, as shown in Fig. 21, the multi-light source formation optical system 2 has the first optical element group 20a including many first optical elements to form the many light sources, and the second optical element group 20c having many second optical elements that illuminate the illuminated surface (mask 5 or wafer 7) by collecting the light beam from the many light sources formed by the first optical element group 20a;

the many first optical elements respectively have the first optical surface having an arc-shaped contour in order to form many light sources by dividing the light beam from the light source means into many arc-shaped light beams in a manner of wavefront dividing; and

the many second optical elements respectively have a second optical surface which is formed in a rectangular shape. As a result, the second optical element group 20c can perform the functions of the condenser optical system 3 required in Figs. 8, 17 and 18, thereby eliminating the structure of the condenser optical system 3.

[0017]

In this case, as set forth in claim 11, it is preferred that the second optical surface of the many second optical elements are respectively formed in a predetermined second reflecting curved surface, and

the predetermined second reflecting curved surface is arranged along a standard curved surface of the second optical element group.

Moreover, in the invention as set forth in claim 12, as shown in Fig. 20, an auxiliary multi-light source formation optical system 120 is positioned in an optical path between the light source means (10-15) and the multi-light source formation optical system 2, and

the auxiliary multi-light source formation optical system 120 is structured to have a first auxiliary optical element group 120a including many first auxiliary optical elements. By an act of this auxiliary multi-light source formation optical system 120, more light sources can be formed in the multi-light source formation optical system 2, and thus the arc-shaped illumination region formed on the illuminating surface (mask or wafer 7) can become more uniform.

[0018]

In the invention set forth in claim 13, as shown in Figs. 17 and 18, a changing means (AS1, AS2, 51 and 60) for changing a shape and a size of a surface light source composed by the many light sources formed by the multi-light source formation optical system 2 is positioned in an optical system between the light source means and the illuminated surface. As a result, appropriate illuminations conforming to various illuminated conditions can be performed to the illuminated surface (mask 5 or wafer 7).

[0019]

Furthermore, in the invention as set forth in claim 14, when the illumination device as set forth in any of claims 1-13, a mask stage MS which holds the mask 5 arranged at the illuminated surface to be illuminated by the illumination device, a substrate stage WS which holds the photosensitive substrate 7, a projection system 6 which projects a predetermined pattern formed in the mask 5 onto the photosensitive substrate, and a predetermined pattern formed in the mask 5 are projected onto the photosensitive substrate 7, driving devices (D_1, D_2) are provided which relatively move the mask stage MS and the substrate stage WS with respect to the projection system 6. By so doing, an exposure apparatus with high throughput can be obtained.

[0020]

In the invention as set forth in claim 15, by using the exposure apparatus as set forth in claim 14, in a method of fabricating a semiconductor device, a step of exposing a pattern of the mask 5 onto the photosensitive substrate 7 via the projection system 6 is included. By so doing, a desired semiconductor device can be fabricated.

[0021]

[Embodiments]

The following explains embodiments of this invention with reference to Figs. 1-4. Fig. 1 is a diagram showing a schematic structure of a first embodiment according to this invention. Fig. 2 is a front view showing a structure of a reflecting element group 2 as a multi-light source formation optical system (optical integrator). Figs. 3(a) and (b) are diagrams showing a structure of the respective reflecting elements E_1 which structure a reflecting type optical element group 2. Fig. 4 is a diagram showing the operation (or "the action") of a reflecting element group 2 as a multi-light source image formation optical system (optical integrator) shown in Fig. 1.

[0022]

As shown in Fig. 1, a laser light beam (parallel light beam) which is provided from a light source means, such as a laser light source or the like, which provides a laser light beam having a wavelength of 200 nm or less is incident substantially perpendicular to the reflecting element group 2, which serves as a multi-light source formation optical system (optical integrator).

Additionally, as a light source means, for example, an ArF excimer laser which provides a laser light beam having a wavelength of 193 nm, an F_2 laser which provides a laser light beam having a wavelength of 157 nm, or the like can be used.

[0023]

Here, the reflecting element group 2 is constituted as many reflecting elements (optical elements) E two-dimensionally arranged in a dense manner along a predetermined first reference plane P_1 perpendicular to a YZ plane. Specifically, as shown in Fig. 2, the reflecting element group 2 has many reflecting elements E having a reflecting curved surface whose contour (outer appearance) is formed in an arc shape. Additionally, this reflecting element group 2 has five columns, arranged along the Y direction, of many reflecting elements, in which many reflecting elements are arranged in a Z direction. Additionally, the five columns of reflecting elements are constituted so as to have a substantially round shape as a whole.

[0024]

Furthermore, a contour shape (arc shape) of each of the reflecting elements E is approximately similar in shape to an arc-shaped illumination region IF formed on a reflecting mask 5 as an illuminated surface which will be described later.

As shown in Figs. 3(a) and (b), the respective reflecting elements have a shape in which part of the reflecting curved surface of a predetermined radius of curvature R_E in a predetermined region which is decentered from the optical axis Ax_E is cut out so that a contour (outer shape) forms an arc shape, and a center C_E of this arc-shaped reflecting element E is located at height h_E from the optical axis Ax_E. Therefore, an eccentric reflecting surface RS_E of the respective reflecting elements E is constituted by an eccentric aspherical mirror having a predetermined radius of curvature R_E as shown in Fig. 3(b). Furthermore, RS_E in Fig. 3(b) shows an effective reflecting region of the reflecting elements E in which a light beam to be incident from the light source means 1 is effectively reflected.

[0025]

Furthermore, as shown in Fig. 3(b), a laser light beam (parallel light beam) L which is incident in a direction parallel to the optical axis Ax_E of the reflecting element E forms a light source image I which is condensed to a focal point F_E on the optical axis Ax_E of the reflecting element E. Additionally, the focal length f_E of the reflecting element E is a distance between a vertex O_E of the reflecting curved surface of the reflecting element E and the focal point F_E of the reflecting curved surface of the reflecting element E. If a radius of curvature R_E of the reflecting curved surface of the reflecting element E is the distance, the following equation (1) can be established.

(1) $f_E = -R_E / 2$

In Fig. 1, laser light (parallel light beam) which is incident substantially perpendicular to the reflecting element group 2 is divided into arc-shaped light beams in a manner of wavefront dividing by a reflecting operation (or act) of the many reflecting elements E, whereby many light source images corresponding to the number of the many reflecting elements E are formed at a position P_2 shifted from the incident light beam. In other words, if a laser light beam is incident from a direction parallel to the respective optical axes Ax_E of the many reflecting elements E which structure the reflecting element group 2, the light source image I is respectively formed in a plane P_2 passing through the focal point F_E on the respective optical axes Ax_E by a reflecting condensing operation (or action) of the respective reflecting elements E. In the plane P_2 in which many light source images I are formed, many

secondary light sources are substantially formed. Therefore, the reflecting element group 2 functions as a light source image formation optical system which forms many light source images I, that is, a multi-light source formation optical system which forms many secondary light sources.

[0026]

The light beam from the many light source images I is incident to a condenser reflecting mirror 3 having an optical axis Ax_C and which serves as a condenser optical system. This condenser reflecting mirror 3 is constituted by one spherical mirror having an effective reflecting surface at a position distant from the optical axis Ax_C, and this spherical mirror has a predetermined radius of curvature R_c. The optical axis Ax_C of the condenser reflecting mirror 3 passes through a center position (position intersecting the plane P_2, in which the light source image R is formed, with the optical axis Ax_C) in which many light source images I are formed by the optical element group 2. However, the focal point of the condenser reflecting mirror 3 exists on this optical axis Ax_C.

[0027]

Furthermore, the optical axis Ax_C of the condenser reflecting mirror 3 is parallel to the respective optical axes Ax_{E1} of the many optical elements E_1 structuring the optical element group 2.

Additionally, after the respective light beams from the many light source images I are respectively reflectingly condensed by the condenser reflecting mirror 3, the reflecting type mask 5 as an illuminated surface is superimposingly illuminated in an arc shape via a flat mirror 4 as a deflecting mirror. Fig. 4 shows an arc-shaped illumination region IF formed on the reflecting type mask 5 when it is seen from a direction shown by arrow A of Fig. 1, that is, from the rear surface of the reflecting type mask 5. A center of curvature O_{IF} of the arc-shaped illumination region IF exists on the optical axis Ax_P of the projection system shown in Fig. 1. Furthermore, in case the flat mirror 4 of Fig. 1 is removed, the illumination region IF is formed at a position of the irradiating surface IP of Fig. 1, and the center of curvature O_{IF} of the illumination region IF exists on the optical axis Ax_C of the condenser optical system 3.

[0028]

Therefore, in the example shown in Fig. 1, the optical axis Ax_C of the condenser optical system 3 is not 90° deflected by the flat mirror 4, but if the optical axis Ax_C of the

condenser optical system 3 is 90° deflected by an imaginary reflecting surface 4a of the flat mirror 4 shown in Fig. 1, the optical axis Ax_C of the condenser optical system 3 and the optical axis Ax_P of the projection system 6 are coaxial on the reflecting mask 5. Because of this, it can be said that these optical axes (Ax_c, Ax_P) are optically coaxial. Therefore, the condenser optical system 3 and the projection system 6 are arranged so that the respective optical axes (Ax_c, Ax_P) optically pass through the center of curvature O_{IF} of the arc-shaped illumination region IF.

[0029]

In the surface of the reflecting type mask 5, a predetermined circuit pattern is formed. This reflecting type mask 5 is held by a mask stage MS which is two-dimensionally movable in an XY plane.

Light reflected by this reflecting type mask 5 is imaged onto a wafer W coated by a resist and thus is a photosensitive substrate, via the projection system 6. Here, an arc-shaped pattern image of the reflecting mask 5 is projectingly transferred. The wafer 7 is held by a substrate stage WS which is two-dimensionally movable in the XY plane.

[0030]

Here, the mask stage MS is two-dimensionally moved along the XY plane via a first driving system D_1, and the substrate stage WS is two-dimensionally moved along the XY plane via a second driving system D_2. The respective driving amounts are controlled by a control system 8 with respect to the two driving systems (D_1, D_2).

Therefore, the control system 8 can move the mask stage MS and the substrate stage WS in a reverse direction (arrow direction) via the two driving systems (D_1, D_2), so the entire pattern formed on the reflecting type mask 5 is scanningly exposed onto the wafer W via the projection system 6. By so doing, a desired circuit pattern, in a photolithography process which fabricates a semiconductor device, is transferred onto the wafer W, so a desired semiconductor device can be fabricated.

[0031]

The projection system 6 having the optical axis Ax_P is constituted by an off-axis type reduction system having four aspherical mirrors (6a-6d) having an effective reflecting surface at a position distant from the optical axis Ax_c. First, third, and fourth aspherical mirrors (6a, 6c, 6d) are constituted by a concave surface type aspherical mirror, and a second aspherical mirror 6b is constituted by a convex surface type aspherical mirror. A pupil of the projection

system 6 exists on a reflecting surface of the third aspherical mirror 6c, and an aperture diaphragm or the like is arranged at a position P_S of this pupil.

[0032]

The following explains an operation of the optical element group 2 shown in Fig. 1 with reference to Fig. 5.

Fig. 5 is a diagram showing enlargement of a portion of an illumination device which illuminates the reflecting mask 5 shown in Fig. 1. Fig. 5 omits a flat mirror 4 in order to clarify the explanation. Furthermore, the reflecting element group 2 is constituted by three reflecting elements (E_a-E_c).

[0033]

As explained in Fig. 1, the reflecting element group 2 includes three reflecting elements (E_a-E_c) arranged along a predetermined reference plane P_1, and the predetermined reference plane P_1 is parallel to a plane (YZ plane) passing through a focal point (position of the center of curvature) P_2 of the respective reflecting elements (E_a-E_c).

As shown in Fig. 5, the laser light beam (parallel light beam) which has been incident to the reflecting element E_a within the reflecting element group 2 is divided into arc-shaped light beams in a manner of wavefront dividing so as to correspond to a contour shape of the reflecting surface of the reflecting element E_a, and the wavefront-divided arc-shaped light beams (light beam shown by solid lines) form a light source image I_a by a condensing operation of a reflecting surface of the reflecting element E_a. After that, the light beam from the light source image I_a is condensed by the reflecting surface of the condenser optical system 3, and the reflecting type mask 5 is illuminated in an arc shape from an oblique direction. Furthermore, the paper plane direction of Fig. 5 is a width direction of an arc-shaped illumination region formed on the reflecting type mask 5.

[0034]

Furthermore, the laser light beam (parallel light beam) which is incident to the reflecting element E_C within the reflecting element group 2 is divided into arc-shaped light beams in a manner of wavefront dividing so as to correspond to a contour shape of the reflecting surface of the optical element E_C. The wavefront-divided arc-shaped light beams (light beam shown by solid lines) form a light source image I_c by a condensing operation of the reflecting surface of the reflecting element E_c. After that, each light beam from the light source image I_c is condensed by the reflecting surface of the condenser optical system 3, and

the reflecting type mask 5 is illuminated in an arc shape by superimposing the light beams on an arc-shaped illumination region shown by solid lines.

[0035]

Thus, the light which went through the respective reflecting element 5 within the reflecting element group 2 is superimposingly illuminated in an arc shape on the reflecting type mask 5, so uniform illumination can be accomplished. Additionally, as shown in Fig. 1, the light source image formed by the respective reflecting elements within the reflecting element group 2 is re-imaged into a position P_s (entrance pupil of the projection system 6) of the pupil of the projection system 6, so that a so-called Koehler illumination can be accomplished.

[0036]

As shown in the above-mentioned first embodiment, in order to expose a pattern of the mask 5 onto the photosensitive substrate 7, even if the illumination device and projection system are entirely constituted by reflecting type members and reflecting type elements, by substantially maintaining the condition of Koehler illumination, an arc-shaped uniform illumination region can be effectively formed on the mask.

Furthermore, by orthogonally projecting a projective relationship of the condenser optical system 3, the reflecting type mask 5 can be illuminated in a uniform numerical aperture NA regardless of the direction.

[0037]

Furthermore, as shown in Fig. 2, many reflecting elements E are densely arranged such that an outer shape (contour) of the reflecting element group 2 is substantially round-shaped, so an outer shape (contour) of a secondary light source formed by many light source images formed at a position P_2 is substantially round-shaped. Therefore, by simultaneously orthogonally projecting a projective relationship of the condenser optical system 3 and forming an outer shape (contour) of the secondary light source, spatial coherency within the illumination region IF formed on the mask 5 can be uniform regardless of the location and the direction.

[0038]

Furthermore, a shape of a reflecting surface of the respective reflecting elements within the reflecting element group 2 is constituted so that the projective relationship becomes the same as the condenser optical system 3, so distortion aberration cannot be generated in the reflecting element group 2 and the condenser optical system 3, and illuminance in the arc-shaped illumination region formed on the reflecting type mask 5 can be further uniform.

Thus, an example was described in which the condenser mirror which structures the condenser optical system 3 and the respective reflecting elements E which structure the reflecting element group 2 are eccentric spherical reflecting surfaces, but they also can be aspherical.

[0039]

Here, specific numerical values are listed for the condenser optical system 3 and the reflecting element group 2 within the exposure apparatus shown in Fig. 1. The following numerical value example shows a case when the condenser mirror which structures the respective reflecting elements E and the condenser optical system 3 which structures the reflecting element group 2 are aspherical.

As shown in Fig. 4, an arc curvature R_{IF} of the arc-shaped illumination region IF formed on the reflecting mask 5 is 96 mm, angle α_{IF} of the arc-shaped illumination region IF is 60°, a length L_{IF} between both ends of the arc-shaped illumination region IF is 96 mm, an arc width t_{IF} of the illumination region IF is 6 mm, an illumination numerical aperture NA on the reflecting mask 5 is 0.015, inclination of a main light beam of illumination light with respect to a normal line of the reflecting mask 5 is 30 mrad (in other words, the entrance pupil position of the projection system 6 is 3119 mm from the reflecting mask 5), and a light beam diameter ϕ supplied from the laser light source is approximately 42 mm.

[0040]

Furthermore, as shown in Fig. 6(a), a reflecting curved surface (aspherical) of the reflecting element E within the reflecting element group 2 is AS_E, a reference spherical surface in a vertex O_E of the reflecting curved surface of the reflecting element E is S_E, a center of curvature of the reference spherical surface is O_{RE}, and an XY coordinate system is considered in which a direction passing through the vertex O_E of the reflecting curved surface of the reflecting element E and perpendicular to a contact plane in the vertex O_E of the reflecting curved surface of the reflecting element E is an X axis (the optical axis Ax_E of the reflecting element E is an X axis), a direction passing through the vertex O_E of the reflecting curved surface of the reflecting element E and parallel to a contact plane in the vertex O_E of the reflecting curved surface of the reflecting element E is the Y axis, and the vertex O_E of the reflecting curved surface of the reflecting element E in which the X and Y axes are intersected is the origin.

[0041]

Here, Fig. 6(a) shows a cross-sectional view of the reflecting curved surface of the reflecting element E within the reflecting element group 2. Fig. 6(b) shows a front view of the reflecting element E in the reflecting element group 2.

When a distance along a direction of an X axis (optical axis Ax_E) up to the reflecting surface (aspherical) of the reflecting element E from the contact plane in the vertex O_E of the reflecting curved surface of the reflecting element E is x, a distance along a direction of a Y axis up to the reflecting surface (aspherical) of the reflecting element E from the X axis (optical axis Ax_E) is y, a radius of curvature (reference radius of curvature of the reflecting element E) of the reference spherical surface S_E going through the vertex O_E of the reflecting curved surface of the reflecting element E is R_E, and aspherical coefficients C_2, C_4, C_6, C_8, and C_{10}, a reflecting surface of the respective reflecting elements E which structure the reflecting element group 2 is constituted by an aspherical surface which can be expressed by the following aspherical surface equation.

$$x(y) = (y^2 / R_E) / [1 + (1 - y^2 / R_E^2)^{0.5}] + C_2 y^2 + C_4 y^4 + C_6 y^6 + C_8 y^8 + C_{10} y^{10}$$

$R_E = -183.3211$

$C_2 = -5.37852 \times 10^{-4}$

$C_4 = -4.67282 \times 10^{-8}$

$C_6 = -2.11339 \times 10^{-10}$

$C_8 = 5.71431 \times 10^{-12}$

$C_{10} = -5.18051 \times 10^{-14}$

As shown in Fig. 6(a), the respective reflecting elements E which structure the reflecting element group 2 have a reflecting cross-sectional shape sandwiched by height y_1 from the optical axis Ax_E and height y_2 from the optical axis Ax_E in a mirror cross-sectional direction. In a front direction as shown in Fig. 6(b), an arc-shaped aspherical eccentric mirror is constituted in which arc open angle α_E is 60°, and the length between both arc ends is 5.25 mm. Furthermore, height y_1 from the optical axis Ax_E is 5.085 mm, and height y_2 from the optical axis Ax_E is 5.415 mm.

[0042]

In this case, the light source image I formed by the reflecting element E is positioned and distant from the vertex O_E of the reflecting curved surface of the reflecting element E by

only 76.56 mm ($=x_I$) in a direction of the optical axis Ax_E of the reflecting element E. In a direction perpendicular to the optical axis Ax_E of the reflecting element E, the light source image I is positioned on the optical axis Ax_E distant from the arc center diameter of the reflecting element E by 5.25 mm. Furthermore, the position of the light source image I in a direction perpendicular to the optical axis Ax_E of the reflecting element E is positioned on the optical axis Ax_E distant from the arc outer diameter of the reflecting element E by 5.085 mm ($=y_1$) and positioned on the optical axis Ax_E distant from the arc outer diameter of the reflecting element E by 5.415 mm ($=y_2$).

[0043]

Furthermore, as shown in Fig. 2, by arranging many eccentric aspherical type reflecting elements E having the above-mentioned dimension, a desired reflecting element group 2 can be structured.

The following shows a specific numerical value example of the condenser mirror 3 as a condenser optical system in the case of using the reflecting elements E having many eccentric aspherical surfaces with the above-mentioned dimension.

[0044]

As shown in Fig. 7, the reflecting curved surface (aspherical surface) of the condenser mirror 3 is AS_C, a reference spherical surface in the vertex O_C of the reflecting curved surface of the condenser mirror 3 is S_C, a center of curvature of a reference spherical surface is O_{RC}, an XY coordinate system is considered in which a direction passing through the vertex O_C of the reflecting curved surface of the condenser mirror 3 and perpendicular to the contact plane in the vertex O_C of the reflecting curved surface of the condenser mirror 3 is an X axis (the optical axis Ax_C of the condenser mirror 3 is an X axis), a direction passing through the vertex O_C of the reflecting curved surface of the condenser mirror 3 and parallel to a contact plane in the vertex O_C of the reflecting curved surface of the condenser mirror 3 is a Y axis, and the vertex O_C of the reflecting curved surface of the condenser mirror 3 in which the X axis and the Y axis are intersected is an origin.

[0045]

Here, Fig. 7 shows a cross-sectional view of the reflecting curved surface of the condenser mirror 3.

When a distance along a direction of an X axis (optical axis Ax_C) up to the reflecting surface (aspherical surface) of the condenser mirror 3 from the contact plane in the vertex O_C

of the reflecting curved surface of the condenser mirror 3 is x, a distance along a direction of a Y axis up to the reflecting surface (aspherical surface) of the condenser mirror 3 from the X axis (optical axis Ax_C) is y, a radius of curvature (a reference radius of curvature of the condenser mirror 3) of a reference spherical surface going through the vertex O_C of the reflecting curved surface of the condenser mirror 3 is R_C, and aspherical coefficients are C_2, C_4, C_6, C_8, and C_{10}, the reflecting surface of the condenser mirror 3 is constituted by an aspherical surface which can be expressed by the following aspherical equation.

$$X(y) = (y^2 / R_c) / [1 + (1 - y^2 / R_E^2)^{0.5}] + C_2 y^2 + C_4 y^4 + C_6 y^6 + C_8 y^8 + C_{10} y^{10}$$

$R_C = -3518.74523$

$C_2 = -3.64753 \times 10^{-5}$

$C_4 = -1.71519 \times 10^{-11}$

$C_6 = 1.03873 \times 10^{-15}$

$C_8 = -3.84891 \times 10^{-20}$

$C_{10} = 5.12369 \times 10^{-25}$

However, the light source image I formed by the reflecting element group 2 is formed in the surface P_2 perpendicular to the optical axis Ax_c of the condenser mirror 3, the surface P_2 in which this light source image I is formed is removed by 2009.8 mm (x_{IC}) along the optical axis Ax_c from the vertex O_c of the reflecting curved surface of the condenser mirror 3.

[0046]

An arc-shaped irradiating region IF in which an illumination distribution and spatial coherency are uniform is formed by an eccentric aspherical type condenser mirror 3 and the reflecting element group 2 which is constituted by many reflecting elements E having an eccentric aspherical type reflecting surface shown by the above-mentioned numerical value example. At this time, as shown in Fig. 7, the center C_{IF} in the width direction of the arc-shaped irradiating region IF formed by the condenser mirror 3 is separated by 1400 mm ($=x_M$) from the vertex O_C of the reflecting curved surface of the condenser mirror 3, and in the height direction of the optical axis Ax_C of the condenser mirror 3, it is located at a position of 96 ($=y_{MC}$) from the optical axis Ax_C.

[0047]

According to the above-mentioned structure, an illumination region IF can be formed in which illumination and spatial coherency are uniform on the reflecting type mask 5.

Furthermore, when the focal length of the respective optical elements E which structure the optical element group 2 is f_F and the focal length of the condenser optical system 3 is f_C, it is preferable that the relationship of the following condition (2) can be satisfied.

(2) $0.01 < | f_F/f_C | < 0.5$

If the maximum of this condition (2) is exceeded, when the respective optical elements which structure the optical element group 2 have an appropriate power, the focal length of the condenser optical system becomes too short. Because of this, aberration is significantly generated in the condenser optical system, so it is difficult to form an arc-shaped uniform illumination region on the mask 5. On the other hand, if the minimum of condition (2) is not met, when the respective optical elements which structure the optical element group have an appropriate power, the focal length of the condenser optical system becomes too long, the condenser optical system itself becomes too large, and it is difficult to structure a compact device.

[0048]

For example, a corresponding value of the above-mentioned condition (2) is listed in accordance with the numerical value example of the condenser mirror 3 and the respective optical elements E which structure the above-mentioned optical element group 2.

As mentioned earlier, a radius of curvature R_E of the respective optical elements which structure the optical element group 2 is -183.3211 mm, so the focal length f_F of the reference of the optical element E is 91.66055 mm ($f_F = -R_E / 2$). Additionally, the radius of curvature of the condenser mirror 3 is -3518.74523 mm, so the focal length f_C of the reference of the optical element E is 1759.3726 mm ($f_C = -R_C / 2$). Therefore, $| f_F/f_C | = 0.052$ is established, the relationship which is shown in the above-mentioned condition is satisfied, and while a desired illumination region is maintained, a compact device is structured.

[0049]

The following explains a second embodiment according to this invention with reference to Figs. 8, 9(a) and (b), 10(a) and (b), and 11(a) and (b).

In the above-mentioned first embodiment, an example is shown in which the multi-light source formation optical system (optical integrator) is constituted by one reflecting element group 2 only, but in the second embodiment, an example is shown in which the multi-light source formation optical system (optical integrator) is constituted by two reflecting element groups (20a, 20b).

[0050]

Fig. 8 is a diagram showing a schematic structure of a second embodiment according to this invention. Figs. 9(a) and (b) are front views showing structures of two reflecting element groups (20a, 20b) as a multi-light source formation optical system (optical integrator). Figs. 10(a) and (b) are diagrams showing the structures of the respective reflecting elements E_1 which structure the first reflecting element group 20a. Figs. 11(a) and (b) are diagrams showing the structures of the respective reflecting elements E2 which structure the second reflecting element group 20b. Fig. 12 is a diagram showing an operation of two reflecting element groups (20a, 20b) as a multi-light source formation optical system (optical integrator) shown in Fig. 8.

[0051]

As shown in Fig. 8, an X-ray radiation device 1 as a light source means is a laser plasma X-ray source which radiates X ray having a wavelength of 10 nm-15 nm, a synchrotron generation device which provides radiation light having a wavelength of 10 nm-15 nm, or the like. Radiation light (X-ray) provided from the X-ray radiation device 1 is radiated toward the multi-light source formation optical system (optical integrator) 2.

[0052]

Here, the multi-light source formation optical system (optical integrator) 2 is constituted by the first reflecting element group 20a and the second reflecting element group 20b.

First, the first reflecting element group 20a is explained. With respect to the first reflecting element group 20a, many first reflecting elements (optical elements) E_1 along a predetermined reference plane P_a perpendicular to a YZ plane are two-dimensionally arranged in a dense manner. Specifically, as shown in Fig. 9(a), the first reflecting element group 20a has many reflecting elements E_1 having a reflecting curved surface in which a contour (outer shape) is formed in an arc shape. Furthermore, there are five rows of the first reflecting element group 20a, in which many first reflecting elements are arranged along the Z direction,

the rows arranged along the Y direction. Furthermore, five rows of the first reflecting elements are constituted so as to have a substantially round shape as a whole.

[0053]

Furthermore, the contour shape (arc shape) of the reflecting elements E is similar to the shape of the arc-shaped illumination region IF formed on the reflecting mask 5 as an illuminated surface which will be discussed later.

As shown in Figs. 10(a) and (b), the respective reflecting elements E_1 have a shape in which part of the reflecting curved surface of a predetermined radius of curvature R_{E1} is cut off in a predetermined region which is decentered from the optical axis Ax_{E1} so that the contour (outer shape) becomes an arc. The center C_{E1} of the arc-shaped reflecting elements E_1 is positioned at height h_E from the optical axis Ax_{E1}. Therefore, the reflecting surface which is decentered from the respective reflecting elements E_1 is constituted by an eccentric spherical surface mirror having a predetermined radius of curvature R_{E1} as shown in Fig. 10(b).

[0054]

Therefore, as shown in Fig. 10(b), radiation light (X-ray) L which is incident from a predetermined oblique direction with respect to the optical axis Ax_{E1} of the reflecting element E_1 forms a light source image I as it is condensed to a surface P_{FO} (position distant from the optical axis Ax_{E1}) perpendicular to the focal point F_{E1} of the reflecting element E_1. Furthermore, the focal length f_{E1} of the reflecting element E_1 at this time is a distance between a vertex O_{E1} of the reflecting curved surface of the reflecting element E_1 and the focal point F_{E1} of the reflecting curved surface of the reflecting element E_1, and if this is a radius of curvature R_{E1} of the reflecting curved surface of the reflecting element E_1, the relationship of the following equation (3) is established.

(3) $f_{E1} = -R_{E1} / 2$

In Fig. 8, radiation light (X-ray) which is obliquely incident from a predetermined direction to the first reflecting element group 20a is divided into arc-shaped light beams in a manner of wavefront dividing by a reflecting operation (or act) of the many reflecting elements E_1, whereby many light source images corresponding to the number of the many reflecting elements E1 are formed at a position P_b (the position of the surface of the respective reflecting elements which structure the second reflecting element group 20b) shifted from the incident light beam. In other words, if radiation light L is incident from an oblique direction

with respect to the respective optical axis Ax_{E1} of the many reflecting elements E_1 which structure the first reflecting element group 20a, the light source image I is respectively formed in the surface P_b passing through the focal point F_{E1} which exists on the respective optical axes Ax_E by the reflecting condensing operation of the respective reflecting elements E_1. Many secondary light sources are substantially formed in the plane P_b (P_{FO} of Fig. 10(b)) in which many light source images I are formed.

[0055]

In the plane P_b in which many light source images I are formed, as shown in Fig. 9(b), the second reflecting element group 20b is arranged.

Here, radiation light supplied from the radiation light source device 1 radiates a light beam having an angle of divergence in a certain range in addition to a parallel light beam. Because of this, in the plane P_b, a certain size of the light source images is formed by the first reflecting element group 20a. Therefore, this second reflecting element group 20b functions as a field mirror group in order to effectively use radiation light supplied from the radiation light source device 1. That is, many second reflecting elements E_2 which structure the second reflecting element group 20b function as a field mirror.

[0056]

The structure of the second reflecting element group 20b is explained. With respect to the second reflecting element group 20b, many second reflecting elements (optical elements) E_2 along a predetermined second reference plane (surface P_b in which many light source images I are formed) perpendicular to the YZ plane are two-dimensionally arranged in a dense manner. Specifically, as shown in Fig. 9(b), the second reflecting element group 20b has many reflecting elements E_2 having a reflecting curved surface in which a contour (outer shape) is formed in a rectangular shape. Furthermore, the second reflecting element group 20b has five rows, arranged in the Y direction, of many second reflecting elements arranged along the Z direction. Furthermore, the five rows of the second reflecting elements are constituted so as to be a substantially round shape as a whole.

[0057]

That is, many second reflecting elements E_2 which structure the second reflecting element group 20b are respectively arranged opposite to the many first reflecting elements E_1 which structure the first reflecting element group 20a, in a one-to-one relationship.

Here, as shown in Figs. 11(a) and (b), the respective reflecting elements E_2 have a shape in which part of the reflecting curved surface of a predetermined radius of curvature R_{E2}

is cut out in a predetermined region including the optical axis Ax_{E2} so that the contour (outer shape) becomes a rectangular shape. The center C_{E2} of the rectangular-shaped reflecting element E_2 matches the optical axis Ax_{E2} of this reflecting element E_2. Therefore, as shown in Figs. 11(a) and (b), the reflecting surface of the respective reflecting elements E_2 is constituted by a coaxial spherical mirror having a predetermined radius of curvature R_{E2}.

[0058]

Furthermore, a function as a light source image formation optical system in which many light source images I are formed, that is, a multi-light source formation optical system which forms many secondary light sources is obtained by two reflecting element groups of the first and second reflecting element groups.

A light beam from many light source images I reflected by the second reflecting element group 20a is incident to a condenser reflecting mirror 3 having an optical axis Ax_c as a condenser optical system. This condenser reflecting mirror 3 is constituted by one eccentric spherical surface mirror which is decentered with respect to the optical axis Ax_c. This eccentric spherical mirror has a predetermined radius of curvature R_c. The focal point of this condenser reflecting mirror 3 matches the secondary light source surface P2 in which many light source images I are formed by the second optical element group 20a. The center of curvature O_c of the condenser reflecting mirror 3 exists at the center position (position in which the optical axis Ax_c and the surface P_2 in which the light source image I is formed are intersected) of many light source images I formed on the second reflecting element group or the center of the optical element group 2.

[0059]

Furthermore, the optical axis Ax_c of the condenser reflecting mirror 3 is parallel to the respective optical axes Ax_{E1} of the many optical elements E1 which structure the first optical element group 20a, but is not parallel to the respective optical axes Ax_{E2} of the many optical elements E2 which structure the second optical element group 20b. That is, the respective optical axes Ax_{E2} of the many optical elements E_2 which structure the second optical element group 20b is inclined by half the incident angle of the light beam as if the obliquely incident light beam were perpendicularly incident.

[0060]

After the respective light beams from many light source images I reflected by the second reflecting element group 20a are respectively reflectingly condensed by the condenser reflecting mirror 3, the reflecting type mask 5 as an illuminated surface is superimposingly

illuminated in an arc shape via the flat mirror 4 as a deflecting mirror. Fig. 4 shows an arc-shaped illumination region IF formed on the reflecting type mask 5 when seen from a direction shown by arrow A of Fig. 8, that is, the rear surface of the reflecting type mask 5. The center of curvature O_{IF} of the arc-shaped illumination region IF exists on the optical axis Ax_p of the projection system shown in Fig. 1. Furthermore, if the flat mirror 4 of Fig. 8 is removed, the irradiating region IF is formed at a position of the irradiating surface IP of Fig. 8, and the center of curvature O_{IF} of the illumination region IF at this time exists on the optical axis Ax_C of the condenser optical system 3.

[0061]

Therefore, in the example shown in Fig. 8, the optical axis Ax_C of the condenser optical system 3 is not 90° deflected by the flat mirror 4, but if the optical axis Ax_C of the condenser optical system 3 is 90° deflected by an imaginary reflecting surface 4a of the flat mirror 4 shown in Fig. 8, the optical axis Ax_C of the condenser optical system 3 and the optical axis Axp of the projection system 6 are coaxial on the reflecting mask 5. Because of this, it can be said that these optical axes (Ax_C, Ax_P) are optically coaxial. Therefore, the condenser optical system 3 and the projection system 6 are arranged so that the respective optical axes (Ax_C, Ax_P) optically pass through the center of curvature O_{IF} of the arc-shaped illumination region IF.

[0062]

Furthermore, in the surface of the reflecting type mask 5, a predetermined circuit pattern is formed, and this reflecting type mask 5 is held by a mask stage MS which can be two-dimensionally moved within the XY plane.

Light which has reflected from this reflecting type mask 5 is imaged onto the wafer 7 coated by resist as a photosensitive substrate via the projection system 6. Here, a pattern image of the arc-shaped reflecting mask 5 is projectingly transferred. The wafer 7 is held by a substrate stage WS which can be two-dimensionally moved within the XY plane.

[0063]

Here, the mask stage MS is two-dimensionally moved within the XY plane via the first driving system D_1, and the substrate stage WS is two-dimensionally moved within the XY plane via the second driving system D_2. In these two driving systems (D_1, D_2), the respective driving amounts are controlled by a control system 8.

Therefore, in the control system 8, by moving the mask stage MS and the substrate stage WS in directions opposite to each other (arrow direction) via the two driving systems (D_1, D_2), the entire pattern formed on the reflecting type mask 5 is scanningly exposed onto the wafer W via the projection system 6. By so doing, a desired circuit pattern in a photolithography process which fabricates a semiconductor device is transferred onto the wafer W, so a desired semiconductor device can be fabricated.

[0064]

As explained in the first embodiment, the projection system 6 having the optical axis Ax_p is constituted by an off-axis type reduction system having four aspherical surface mirrors (6a-6d) having an effective reflecting surface at a position separated from the optical axis Ax_C. The first, third, and fourth aspherical mirrors (6a, 6c, 6d) are constituted by concave surface type aspherical mirrors, and the second aspherical surface mirror 6b is constituted by a convex surface type aspherical mirror. The pupil of the projection system 6 exists on the reflecting surface of the third aspherical mirror 6c, and an aperture diaphragm or the like is arranged at the position P_S of this pupil.

[0065]

The following explains an operation of the first and second reflecting element groups (20a, 20b) of an example shown in Fig. 8 with reference to Fig. 12.

Fig. 12 is a diagram showing enlargement of a part of an illumination device which illuminates the reflecting mask 5 shown in Fig. 8. In order to clarify the explanation, Fig. 12 omits a flat mirror 4. Furthermore, the first reflecting element group 20a is constituted by two reflecting elements (E_{a1}, E_{b1}), and the second reflecting element group 20b is constituted by two reflecting elements (E_{a2}, E_{b2}).

[0066]

The first reflecting element group 20a includes two first reflecting elements (E_{a1}, E_{b1}) arranged along a predetermined first reference plane P_a, and the predetermined reference plane P_a is at a position which is optically conjugate to the reflecting mask 5 as an illuminated surface or in the vicinity of the conjugate position.

Additionally, the second reflecting element group 20b includes two first reflecting elements (Ea_2, Eb_2) arranged along a predetermined second reference plane P_b, and the predetermined reference plane P_b is at a position which is optically conjugate to the reflecting mask 6 as an illuminated surface or in the vicinity of the conjugate position.

[0067]

As shown in Fig. 12, radiation light (X ray), shown by solid lines, which is incident from a direction with respect to the reflecting element E_{a1} within the first reflecting element group 20a is divided into arc-shaped light beams in a manner of wavefront dividing so as to correspond to a contour shape of the reflecting surface of the reflecting element E_{a1}, and the wavefront-divided arc-shaped light beam (light beam shown by solid lines) forms a light source image I_1 at one end on the reflecting element E_{a2} within the second reflecting element group 20b by a condensing operation of the reflecting surface of the reflecting element E_{a1}.

[0068]

Furthermore, radiation light (X ray), shown by dotted lines, which is incident from a different direction to the reflecting element E_{a1} within the first reflecting element group 20a is divided into arc-shaped light beams in a manner of wavefront dividing so as to correspond to a contour shape of the reflecting surface of the reflecting element E_{a1}, and the wavefront-divided arc-shaped light beam (light beam shown by dotted lines) forms a light source image I_2 at the other end on the reflecting element E_{a2} within the second reflecting element group 20b by a condensing operation of the reflecting surface of the reflecting element E_{a1}.

[0069]

Therefore, when radiation light within an angle range, shown by dotted lines and solid lines, is incident to the reflecting element E_{a1} within the first reflecting element group 20a, a light source image which is connected between the light source image I_1 and the light source image I_2 is formed on the reflecting element E_{a2} within the second reflecting element group 20b.

After that, the light beam from the two light source images (I_1, I_2) is condensed by a reflecting condensing operation (field mirror operation) of the reflecting element E_{a2} within the second reflecting element group 20b and condensed by the reflecting condensing operation at the reflecting surface of the condenser optical system 3, and the reflecting type mask 5 is arc-illuminated in a superimposed manner from two directions. Additionally, the paper plane direction of Fig. 12 is a width direction of the arc-shaped illumination region formed on the reflecting type mask 5.

[0070]

Additionally, an optical operation (or action) by the reflecting element E_{b2} within the second reflecting element group 20b and the reflecting element E_{b1} within the first reflecting element group 20a is the same optical operation (or action) by the reflecting element E_{a1}

within the second reflecting element group 20a and the reflecting element E_{a2} within the first reflecting element group 20b which were described above. Therefore, explanation is omitted here.

Thus, light from many light source images formed by the two reflecting element groups (20a, 20b) is superimposingly illuminated into an arc shape on the reflecting type mask 5, so that uniform illumination can be effectively accomplished. Furthermore, the light beam path from the light source image is effectively condensed by an operation (field mirror operation) of the respective reflecting elements E within the second reflecting element group 20b, so the size of the condenser optical system 3 can be made compact.

[0071]

Furthermore, as shown in Fig. 8, the light source image which is formed in the surface of the respective reflecting elements within the second reflecting element group 20b is re-imaged into a position P_S (entrance pupil of the projection system 6) of the pupil of the projection system 6, so that so-called Koehler illumination can be accomplished.

As shown in the second embodiment, for example, by using light with an angle of divergence and with a wavelength of 100 nm or less such as X ray, in order to expose a mask pattern onto the photosensitive substrate 7, even if the entire illumination device and projection system are constituted by reflecting type members and reflecting type elements, by substantially maintaining Koehler illumination conditions, an arc-shaped illumination region in which illumination is uniform on the mask can be effectively formed.

[0072]

Furthermore, in the second embodiment, an example as a spherical-shaped reflecting surface is described in which a condenser mirror 3 which constitutes the condenser optical system and the respective reflecting elements (E_1, E_2) which structure the first and second reflecting element groups (20a, 20b) are both eccentric, but needless to say, these can also be aspherical.

Furthermore, in the second embodiment, an example is shown in which the condenser optical system 3 and the projection system 6 are arranged so that the optical axis Ax_C of the condenser optical system 3 is perpendicular to the optical axis Ax_P of the projection system 6. As shown in Fig. 13, by changing arrangement of the deflecting mirror (flat mirror), the condenser optical system 3 and the projection system 6 can also be arranged so that the optical axis Ax_C of the condenser optical system 3 and the optical axis Ax_P of the projection system 6 can be coaxial even in terms of their physical arrangement.

[0073]

Furthermore, the following explains modification of the second embodiment with reference to Figs. 14(a) and (b) and 15.

In this example, in order to further improve illumination effectiveness in the first and second reflecting element groups (20a, 20b) shown in Figs. 9(a) and (b), the first and second reflecting element groups (20a, 20b) shown in Fig. 8 can be constituted as shown in Figs. 14(a) and (b) and 15.

[0074]

First, the structure of the first reflecting element group 20a is explained. As shown in Fig. 14(a), the first reflecting element group 20a has, along the Y direction, three rows of many second reflecting elements, in which many first reflecting elements having an arc-shape contour (outer shape) are arranged along the Z direction.

The first reflecting element row G_{E11} is constituted by many reflecting elements (E_{11a}-E_{11v}). Furthermore, this first reflecting element row G_{E11} is arranged in a state in which arbitrary reflecting elements which constitute the first reflecting element row G_{E11} are rotated by a predetermined amount about an axis A_1 parallel to a Z axis crossing the center (center of the respective reflecting element) of the first reflecting element row.

[0075]

Furthermore, the second reflecting element row G_{E12} is constituted by many reflecting elements (E_{12a}-E_{12y}). Additionally, the second reflecting element row G_{E12} is arranged in a state in which arbitrary reflecting elements which structure the second reflecting element row G_{E12} are rotated by respective predetermined amounts about the axis A_2 parallel to the Z axis crossing the center (center of the respective reflecting elements) of the second reflecting element row.

[0076]

Furthermore, the third reflecting element row G_{E13} is constituted by many reflecting elements (E_{13a}-E_{13v}). Additionally, this third reflecting element row G_{E13} is arranged in a state in which arbitrary reflecting elements which structure the third reflecting element row G_{E13} are rotated by respective predetermined amounts about the axis A_3 parallel to the Z axis crossing the center (center of the respective reflecting elements) of the third reflecting element row.

[0077]

Next, the structure of the second reflecting element group 20a is explained. As shown in Fig. 14(b), the second reflecting element group 20b has nine rows, arranged along the Y direction, in which many second reflecting elements E2 having a substantially square-shaped contour (outer shape) are arranged along the Z direction.

Furthermore, the second reflecting element group 20b has a first part group G_{E21} which is constituted by first-third reflecting element rows, a second part group G_{E22} which is constituted by fourth-sixth reflecting element rows, and a third part group G_{E22} which is constituted by seventh-ninth reflecting element rows.

[0078]

Here, in the surface of the respective reflecting elements E_2 which structure the first part group G_{E21}, a light source image which is condensed by the respective reflecting elements (E_{11a}-E_{11v}) of the first reflecting element row G_{E11} within the first reflecting element group 20a is respectively formed.

Additionally, in the surface of the respective reflecting elements E_2 which structure the first part group G_{E22}, a light source image which is condensed by the respective reflecting elements (E_{12a}-E_{12v}) of the second reflecting element row G_{E12} within the first reflecting element group 20a is respectively formed.

[0079]

Furthermore, in the surface of the respective reflecting elements E_2 which structure the third part group G_{E23}, a light source image which is condensed by the respective reflecting elements (E_{13a}-E_{13v}) of the third reflecting element row G_{E13} within the first reflecting element group 20a is respectively formed.

Specifically, as shown in Fig. 15, the respective reflecting elements (E_{11a}-E_{11k}) which structure the first reflecting element row G_{E11} are arranged in a state in which arbitrary reflecting elements which structure the first reflecting element row G_{E11} are rotated by respective predetermined amounts about the axis A_1 parallel to the Z axis crossing the center (center C_{1a}-C_{1k} of the respective reflecting elements) of the center of the first reflecting element row.

[0080]

For example, the reflecting element E_{11a} is fixed and arranged in a state which is rotated counter clockwise about the axis A_1 by a predetermined amount (micro amount). This

reflecting element E_{11a} forms arc-shaped light source image I_a of a certain size on the uppermost part of the third row of the reflecting element E_2 of the first part group G_{E21}.

Furthermore, the reflecting element E_{11f} is fixed in a state which is rotated counter clockwise about the axis A_1 by a predetermined amount (micro amount). This reflecting element E_{11f} forms a round-shaped light source image I_f on the second reflecting element E_2 from the top of the first row of the first part group G_{E21}.

[0081]

Additionally, the reflecting element E_{11K} is fixed without being rotated about the axis A_1, and the reflecting element E_{11k} forms a round-shaped light source image I_f on the fourth reflecting element E_2 from the top of the second row of the first part group G_{E21}. The optical axis of the reflecting element E_{11k} at this time is parallel to the optical axis of the reflecting elements which structure the first part group G_{E21}.

[0082]

This type of structure shown in Fig. 15 is the same between the second reflecting element row G_{E12} in the first reflecting element group 20a and the second part group G_{E22} and the third reflecting element row G_{E13} in the first reflecting element group 20a and the second part group G_{E23}.

Thus, according to the structure of the first and second reflecting elements (20a, 20b) shown in Figs. 14(a) and (b) and 15, compared to the structure of the first and second reflecting elements (20a, 20b) shown in Fig. 9(a) and (b), it is difficult to eclipse a light source image by the contour (outer shape) of the second reflecting element, so illumination effectiveness can be improved.

[0083]

According to the above-mentioned first and second embodiments, the reflecting elements (E, E_1) having an arc-shaped contour (outer shape) in the first reflecting element group which structure at least part of the multi-light source formation means is constituted by an eccentric mirror which is decentered with respect to the optical axes (Ax_E, Ax_{E1}) of the elements, so it is acceptable to perform aberration correction in only the arc region in an image height (height from the optical axis). Therefore, restrictions on the optical design can be significantly relaxed compared to the case in which a non-eccentric reflecting element is designed. By so doing, aberration can be sufficiently controlled which is generated in the reflecting element of the first reflecting element group. Therefore, in an irradiating surface of

the mask 5 or the like, there is an advantage that extremely desired uniform arc-shaped illumination can be accomplished.

[0084]

Furthermore, as the condenser optical system is also constituted by an eccentric mirror system, aberration which is generated in the condenser optical system can be sufficiently controlled. Therefore, the above-mentioned advantage can be additionally obtained. Furthermore, a condenser optical system can be constituted by one eccentric mirror, but can also be constituted by a plurality of eccentric mirrors.

In addition, if the first and second reflecting element groups are independently or integrally moved by only a micro amount in a predetermined direction (an optical axis of the reflecting element or the direction perpendicular to the optical axis) or at least one of the first and second reflecting element groups is inclined by only a micro amount, an illumination distribution or the like in an arc-shaped illumination region which is formed on an illuminated surface can be adjusted. Furthermore, at least one eccentric mirror which structures a condenser optical system can also be moved or inclined in a predetermined direction (an optical axis of the condenser optical system or the direction perpendicular to the optical axis) by only the micro amount.

[0085]

Furthermore, in order to structure a compact device in which a desired illumination region is maintained, needless to say, it is preferable that the first reflecting element group 20a and the condenser optical system 3 in the second embodiment satisfy the relationship of the above-mentioned condition (2).

In addition, in the above-mentioned respective embodiments, an example is shown in which the first and second optical elements which structure the multi-light source formation optical system are respectively constituted by reflecting mirrors, but they can also be constituted by a refractive lens elements. In this case, needless to say, it is preferable that a cross-sectional shape of the lens elements which structure the first optical element is arcuate.

Moreover, Figs. 19 and 14 respectively show the first optical element group 20a and the second optical element group 20b structured by densely positioning many reflecting elements (E_1 and E_2) so that there are no spaces between them. However, in the second optical element group shown in Figs. 9(b) and 14(b), it is not always necessary to densely position many of the reflecting elements E_2 so that there are not gaps. Below describes the reasons thereof. As described above, many light source images are formed on or near the

second optical element group 20b, as they respectively correspond to each reflecting element E_2. The loss of light amount does not happen as long as these light source images fit in an effective reflecting region of each reflecting element E_2. Therefore, when many light source images are formed discretely on or near the second optical element group 20b with spaces, many reflecting elements E2 in the second optical element group can be positioned discretely with spaces therebetween.

[0086]

Fig. 17 shows an example of modification of a projection exposure device that performs exposure using a step-and-scan method according to the first embodiment shown in Fig. 1. The projection exposure device shown in Fig. 17 uses light (EUV light) in a soft X ray region having a wavelength of about 5nm-20nm to perform exposure by the step-and-scan method. In Fig. 17, the same symbols are used for the members shown in Fig. 1 having the same functions. In addition, in Fig. 17, an optical axis direction of the projection system forming a reduced image of the mask 5 on the wafer 7 is set as a Z direction, a direction towards the plane of the figure orthogonal to this Z direction is set as a Y direction, and a direction perpendicular with the plane of the figure that is orthogonal with these Y and Z directions is set as an X direction. Furthermore, the device shown in Fig. 17 and later-described Figs. 18 and 20-22 is equipped with drive devices (D_1 and D_2) that move the mask stage MS and the substrate stage WS relatively with respect to the projection system 6, as shown in Figs. 1 and 8. These are omitted from Figs. 17, 18, and 20-22.

[0087]

As shown in Fig. 17, the exposure device transfers the entire circuit pattern of the mask 5 onto each of a plurality of shot regions on the wafer 7 by a step-and-scan method, while projecting an image of a part of a circuit pattern drawn on the reflecting type mask 5 as a projection original (mask) onto the wafer 7 as a substrate, through the projection optical system 9.

[0088]

As shown in Fig. 17, because the soft X ray that is the illumination light for exposure is low in permeability with respect to air, the optical path through which the EUV light passes is enclosed by a vacuum chamber 100 so that it is shielded from the open air.

A laser light source 10 has a function to supply a laser beam having a wavelength in the infrared region - the visible region, and may be used in a YAG laser or an excimer laser generated by semiconductor laser excitation. This laser beam is condensed by a light

condensing optical member 11 and condensed at a position 13. A nozzle 12 jets gaseous matter towards the light condensed position 13, and the jetted matter receives a high illuminance laser beam at a position 3. At this time, the jetted matter is heated due to energy of the laser beam, is excited to a plasma condition, and discharges the EUV light when transitioning to a low energy state.

[0089]

An elliptical mirror 14 is positioned around the position 3. The elliptical mirror 14 is positioned such that its first focal point matches substantially with the light condensed position 13. On an internal surface of the elliptical mirror 14, a multi-layer film is provided for reflecting the EUV light. The EUV light reflected here is directed to a parabolic (collimator reflection mirror) 15 after once condensed at the second focal point of the elliptical mirror 14. This reflection mirror 15 is positioned such that its focal point matches substantially with the second focal point of the elliptical mirror 14. A multi-layer film for reflecting the EUV light is provided on the internal surface.

[0090]

The EUV light emitted from the parabolic mirror 15 is directed to a reflecting type fly's eye optical system 2 as an optical integrator in a state that the EUV light is substantially collimated.

The light condensing optical system is composed of the light condensing optical member 11, the elliptical mirror 14 and the parabolic mirror 15.

The reflecting type fly's eye optical system 2 is composed of the first reflecting element group 20a integrated with a plurality of reflecting surfaces (a plurality of reflecting surfaces of the reflection element E_1), and the second reflecting element group 20b having a plurality of reflection surfaces (a plurality of reflecting surfaces of the reflection element E_2) corresponding to the plurality of reflecting surfaces of the first reflecting element group 20a. A multi-layer film for reflecting the EUV light is also provided on the plurality of reflecting surfaces composing the first and second reflecting element groups 20a and 20b.

[0091]

At a position of the reflecting surface of one of the second reflecting element groups 120b structuring the reflecting type fly's eye optical system 2 or a position nearby, a first variable aperture stop AS1 is provided for varying the numerical aperture of a light beam illuminating the reflecting type mask 5 (numerical aperture of the illumination system). This first variable aperture stop AS1 has a substantially circular-shaped variable aperture. The

diameter of the aperture of the first variable aperture stop AS1 becomes variable by a first driving system DR1.

[0092]

The collimated EUV light from the parabolic mirror 15 is wavefront divide by the first reflecting element group 20a, and the EUV light from each reflecting surface is condensed to form a plurality of light source images. A plurality of reflecting surfaces of the second reflecting element group 20b are positioned respectively near the position at which the plurality of light source images are formed. The plurality of reflecting mirrors of the second reflecting element group 20b functions substantially as a field mirror. The reflecting type fly's eye optical system 2 forms many light source images as the secondary light source, based on a substantially parallel light beam from the parabolic mirror 15.

[0093]

The EUV light from the secondary light source formed by the reflecting type fly's eye optical system 2 is directed to a condenser mirror 3 positioned such that the periphery of the position of the secondary light source becomes the focusing position. After the light is reflected and condensed at the condenser mirror 3, it reaches the reflecting type mask 5 via an optical path folding mirror 4. A multi-layer film that reflects the EUV light is provided on a surface of the condenser mirror 3 and the optical path folding mirror. The condenser mirror 3 collects the EUV light generated from the secondary light source and superimposedly and uniformly illuminates a predetermined illumination region of the reflecting type mask 5.

[0094]

On the reflecting type mask 5, a pattern of a multi-layer film that reflects the EUV light is provided. By the EUV light reflected from the reflecting type mask 5 to form an image using the projection system 6, an image of the reflecting type mask 5 is transferred onto the wafer 7 as a photosensitive substrate.

In this embodiment, the illumination system is a non-telecentric system that spatially divides the optical path of the illumination light directed to the reflecting type mask 5 and the EUV light directed towards the projection system 6 as reflected by the reflecting type mask, and the projection system 6 also is non-telecentric on the mask side.

[0095]

Descriptions of the structure of the projection system 6 are omitted since it is the same as the structure of the projection system 6 shown in Fig. 1. However, a multi-layer film that

reflects the EUV light is provided on a surface of four mirrors (6a-6d) structuring the projection system 6 shown in Fig. 17.

The mirror 6c is positioned at a pupil position of the projection system 6 in Fig. 17 or a position nearby, and a second variable aperture stop that varies the numerical aperture of the projection system 6 is provided on or near the reflecting surface of the mirror 6c. The second variable aperture stop AS2 has a substantially circular shaped variable aperture. The diameter of the aperture of the second variable aperture stop AS 2 is varied by the second drive system DR 2.

[0096]

A ratio of the numerical aperture of the illumination system and the numerical aperture of the projection system 6 (coherent factor or σ value) is described below. The σ value is defined by $\sigma = NA1/NA2$ where NA1 is the numerical aperture of the illumination system and NA2 is the numerical aperture of the projection system 6.

Depending on the minuteness of a pattern to be transferred to the wafer 7 or a process by which a pattern is transferred to the wafer 7, it is necessary to vary the ratio of the numerical aperture of the illumination system and the numerical aperture of the projection system 6, and to adjust the resolution or the depth of focus of the projection system 6. Therefore, exposure information (a wafer transfer map including exposure information, etc.) relating to exposure conditions for each wafer sequentially mounted on the wafer stage WS (not shown in Fig. 17) by an undepicted transfer device, and mounting information of various masks sequentially mounted on the mask stage MS are input to a control device MCU via an input device IU, such as a console. The control device MCU determines whether the ratio of the numerical aperture of the illumination system and the numerical aperture of the projection system 6 should be changed, based on the information input from the input device IU, every time when the wafer 7 is mounted on the wafer stage WS (not shown in Fig. 17). If the control device MCU determines that the ratio of the numerical aperture of the illumination system and the numerical aperture of the projection system 6 should be changed, the control device MCU drives at least one of two driving systems (DR1 and DR2) to vary the diameter of the aperture of at least one of the first aperture stop AS1 and the second variable aperture stop AS2. As a result, appropriate exposure can be achieved under various exposure conditions.

[0097]

It is preferable to change the reflecting mirror 15 to a reflecting mirror that has a different focal length in response to the aperture diameter of the first aperture stop AS1 being varied. As a result, a diameter of a light beam of the EUV light entering the reflecting type fly's eye optical system 2 can be changed depending on the size of the aperture of the first aperture stop AS1, and thus, illumination under an appropriate σ value becomes possible while maintaining high illumination efficiency.

[0098]

In the exposure device shown in Fig. 17, it is possible that if a light illuminance distribution on the reflecting type mask 5 or the wafer 7 is uneven so that the distribution is inclined, the inclination of the light illuminance distribution is corrected by making the light beam of the EUV light or the like entering to the reflecting type fly's eye optical system 2 eccentric such that the light beam passes across the reflecting element group 20a. For instance, the inclination of the light illuminance distribution can be corrected by making the parabolic mirror 15 slightly eccentric. That is, when the inclination of the light illuminance distribution is occurring in the left and right directions (X direction) of the arc-shaped illumination region formed on the surface of the reflecting type mask 5 or the surface of the wafer, the inclination of the light illuminance distribution can be corrected by moving the parabolic mirror 15 in the X direction. In addition, if the illuminance is different at a center part and a periphery part in a width direction (Z direction) of the arc-shaped illumination region formed on the surface of the reflecting type mask 5 or the wafer surface, the inclination of the light illuminance distribution can be corrected by moving the parabolic mirror 15 in the Z direction.

[0099]

There are cases in which illumination conditions due to generation of unevenness in the illumination of the arc-shaped illumination region formed on the wafer 7 or the mask 5 is worsened by having the aperture diameter of at least one of the first aperture stop AS1 and the second variable aperture stop AS2 variable. In this case, it is preferable that the unevenness of the illumination and the like of the arc-shaped illumination region be corrected by slightly moving at least one optical member among the parabolic mirror 15, the reflecting type fly's eye optical system 2 and the condenser mirror 3.

[0100]

Next, a first example of modification of the projection exposure device shown in Fig. 17 is described with reference to Fig. 18. In Fig. 18, members having the same functions as the members shown in Fig. 17 are referenced by the same symbols.

The first difference between the exposure device shown in Fig. 17 described above and the exposure device shown in Fig. 18 is that a turret plate 51, on which a plurality of aperture stops (50a-50f) having different shapes and sizes from each other, as shown in Fig. 19, instead of the first aperture stop AS1 positioned on or near the reflecting surface position of one of the second reflecting element groups 20a structuring the reflecting type fly's eye optical system 2, and that the turret plate 51 is made rotatable about a predetermined rotational axis 52 as a center by the first driving system DR1.

[0101]

The second difference from the exposure device shown in Fig. 17 is that an annular light beam conversion unit 60 that converts EUV light having a circular shaped light beam cross section to EUV light having an annular shaped (ring shaped) light beam cross section, is provided so as to be insertable and removable with respect to the illumination optical path, in an optical path between the parabolic mirror 15 and one of the first reflecting element groups 20a structuring the reflecting type fly's eye optical system 2.

[0102]

The annular light beam conversion unit 60 has a first reflecting member 60a having a ring-shaped reflecting surface and a second reflecting member 60b having a conical-shaped reflecting surface. The first reflecting member 60a and the second reflecting member 60b are provided relatively movably along the illumination optical path, in order for a ratio of the inner diameter and the outer diameter of the annular (ring-shaped) EUV light (i.e., annular ratio) entering to the reflecting type fly's eye optical system 2 to be variable.

[0103]

The insertion and removal of the annular light beam conversion unit 60 with respect to the illumination optical path and the relative movement of the first reflecting member 60a and the second reflecting member 60b along the illumination optical path are performed by a third driving system DR3.

The turret plate 51 and the annular light beam conversion unit 60 are described with reference to Figs. 18 and 19.

[0104]

As shown in Fig. 19, the turret plate 51 which has a plurality of aperture stops is provided rotatably about the predetermined axis 52 as the center. As shown in the figure, the aperture stops 50a-50f having different shapes of apertures respectively are provided on the turret plate 51. The aperture stop 50a has an annular shaped (donut shaped) aperture, and the aperture stops 50b and 50e have circular shaped apertures having different diameters, respectively. The aperture stop 50c has four fan-shaped apertures, and the aperture stop 50d has four circular shaped apertures. The aperture stop 50f has an annular ratio (ratio of the outer diameter and inner diameter of the annular shaped aperture) different from the aperture stop 50a.

[0105]

In Fig. 18, the input device inputs information required to select an illumination method on the mask 5 and the wafer 7. For example, the input device IU is for inputting exposure information (e.g., transfer map of a wafer including exposure information) relating to exposition conditions for each wafer sequentially mounted by the undepicted transfer device and mounting information of various masks sequentially mounted on the mask stage MS, in response to the minuteness of a pattern to be transferred on the wafer 7 and a process by which a pattern to be transferred on the wafer 7.

[0106]

In the example shown in Fig. 18, the control device MCU can select the "first annular illumination," the "second annular illumination," the "first normal illumination," the "second normal illumination," the "first special oblique illumination," or the "second special oblique illumination," based on the information input from the input device IU.

Here, the "annular illumination" illuminates EUV light from a diagonal direction to the reflecting type mask 6 and the wafer 7 by making the shape of the secondary light source formed by the reflection fly's eye optical system 2 in an annular shape (donut shape) and thereby improves resolution and depth of focus that the projection system 6 has. In addition, the "special oblique illumination" illuminates the EUV light from a diagonal direction to the reflecting type mask 6 and the wafer 7 by making the secondary light source formed by the reflecting type fly's eye optical system 2 a plurality of discrete eccentric light sources eccentric by a predetermined distance from the center of the secondary light source, and further improves the resolution and the depth of focus that the projection system 6 has. Moreover,

the "normal illumination" illuminates the mask 5 and the wafer 7 with the optimum σ value, by making the secondary light source formed by the reflecting type fly's eye optical system 2 in a substantially circular shape.

[0107]

The control device MCU controls, based on the information input from the input device IU, the first driving system DR1 that rotates the turret plate 51, the second driving system DR2 that changes the aperture diameter of the aperture stop AS2 of the projection system 6, and the third driving system DR3 that inserts and removes the annular light beam conversion unit 60 with respect to the illumination optical path and changes a relative distance between two reflecting members (60a and 60b) at the annular light beam conversion unit 60.

[0108]

Operations of the control device MCU are described below.

If the illumination condition on the mask 5 is set to the normal illumination, the control device MCU selects the "first normal illumination" or the "second normal illumination" based on the information input from the input device IU. Here the difference between the "first normal illumination" and the "second normal illumination" is that the σ value is different.

[0109]

For example, if the control device MCU selects the "first normal illumination," the control device MCU rotates the turret plate 51 by driving the first driving system DR1 such that the aperture stop 50e is positioned at a position of the secondary light source (many light source images) formed on the exit side of the second optical element group 20b structuring one component of the reflecting type fly's eye optical system 2. At the same time, if necessary, the control device MCU changes the aperture diameter of the second aperture stop in the projection system 6 via the second driving system DR2. At this time, if the annular light beam conversion unit 60 is set in the illumination optical path, the control device MCU retracts the annular light beam conversion unit 60 from the illumination path via the third driving system DR3.

[0110]

In accordance with the setting condition of the illumination system described above, the pattern of the reflecting type mask 5 can be exposed onto a photosensitive substrate (wafer) 7 through the projection system 6 under the appropriate "first normal illumination"

condition (appropriate σ value) when illuminating the pattern of the reflecting type mask 5 with the EUV light.

Furthermore, if the control device MCU selects the "second normal illumination," the control device MCU rotates the turret plate 51 by driving the first driving system DR1 such that the aperture stop 50b is positioned at a position of the secondary light source (many light source images) formed on the exit side of the second optical element group 20b structuring one component of the reflecting type fly's eye optical system 2. At the same time, if necessary, the control device MCU changes the aperture diameter of the second aperture stop in the projection system 6 via the second driving system DR2. At this time, if the annular light beam conversion unit 60 is set in the illumination optical path, the control device MCU retracts the annular light beam conversion unit 60 from the illumination path via the third driving system DR3.

[0111]

In accordance with the setting condition of the illumination system described above, the pattern of the reflecting type mask 5 can be exposed onto a photosensitive substrate (wafer) 7 through the projection system 6 under the appropriate "first normal illumination" condition (larger σ value than that used the first normal illumination) when illuminating the pattern of the reflecting type mask 5 with the EUV light.

As described in the example shown in Fig. 17, in the example shown in Fig. 18, it is also preferable to change the reflecting mirror 15 with a reflecting mirror having a different focal length, in response to having the aperture diameter of the first aperture stop AS1 variable. As a result, a diameter of the light beam of the EUV light entering the reflecting type fly's eye optical system 2 can be changed depending on a size of the aperture of the first aperture stop AS1, and thus, illumination under an appropriate σ value can become possible while maintaining high illumination efficiency.

[0112]

When setting the illumination to the reflecting type mask 5 at oblique illumination, the control device MCU selects one of the "first annular illumination," the "second annular illumination," the "first special oblique illumination," and the "second special oblique illumination," based on the information input from the input device IC. The difference between the "first annular illumination" and the "second annular illumination" is that an annular ratio of the secondary light source formed in an annular shape is different. The

difference between the "first special oblique illumination" and the "second special oblique illumination" is that a distribution of the secondary light source is different. That is, the secondary light source in the "first special oblique illumination" is distributed in four fan-shaped regions, and the secondary light source in the "second special oblique illumination" is distributed in four circular-shaped regions.

[0113]

For example, when the "first annular illumination" is selected, the control device MCU rotates the turret plate 51 by driving the driving system DR1 such that the aperture stop 50a is positioned at the position of the secondary light source (many light source images) formed on the exit side of the second optical element group 20b structuring one component of the reflecting type fly's eye optical system 2. Moreover, if the "second annular illumination" is selected, the control device MCU rotates the turret plate 51 by driving the driving system DR1 such that the aperture stop 50f is positioned at the position of the secondary light source (many light source images) formed on the exit side of the second optical element group 20b structuring one component of the reflecting type fly's eye optical system 2. Furthermore, when the "first special oblique illumination" is selected, the control device MCU rotates the turret plate 51 by driving the driving system DR1 such that the aperture stop 50c is positioned at the position of the secondary light source (many light source images) formed on the exit side of the second optical element group 20b structuring one component of the reflecting type fly's eye optical system 2. When the "second special oblique illumination" is selected, the control device MCU rotates the turret plate 51 by driving the driving system DR1 such that the aperture stop 50d is positioned at the position of the secondary light source (many light source images) formed on the exit side of the second optical element group 20b structuring one component of the reflecting type fly's eye optical system 2.

[0114]

When one of the four apertures (50a, 50c, 50d and 50f) is set in the illumination optical path, the control device MCU simultaneously changes the aperture diameter of the second aperture stop in the projection system 6 via the second driving system DR2 if necessary.

Next, the control device MCU performs the setting of the annular light beam conversion unit 60 via the third driving system DR3 and the adjustment of the annular light beam conversion unit 60. The setting and adjustment of the annular light beam conversion unit 60 is performed as described below.

[0115]

First, when the annular light beam conversion unit 60 is not set in the illumination optical path, the control device MCU sets the annular light beam conversion unit 60 in the illumination optical path via the third driving system DR3.

Next, the control device MCU changes a relative space of two reflecting members (60a and 60b) in the annular light beam conversion unit 60 via the third driving system DR3 such that the annular light beam is efficiently directed to the aperture of one of the four aperture stops (50a, 50c, 50d and 50f) set on the exit side of the second optical element group 20b structuring one component of the reflecting type fly's eye optical system 2. As a result, the annular light beam conversion unit 60 can convert the light beam entering it into an annular light beam having an appropriate annular ratio.

[0116]

By the above setting and adjustment of the annular light beam conversion unit 60, the secondary light source formed in the reflecting type fly's eye optical system 2 can be an annular shaped secondary light source having an annular ratio appropriate for each of the four aperture stops (50a, 50c, 50d and 50f). Therefore, the reflective mask and the wafer 7 can be illuminated with inclination under high illumination efficiency.

[0117]

When a plurality of aperture stops (50a-50f) having different shapes and sizes from each other are set in the illumination optical path by the rotation of the turret plate 51, the illumination conditions, such as uneven illumination of the arc-shaped illumination region formed on the wafer 7 or the mask 5 may change. In such a case, it is preferred to slightly move one optical member among the parabolic mirror 15, the reflecting type fly's eye optical system 2 and the condenser mirror 3 to correct the uneven illumination of the arc-shaped illumination region.

[0118]

Moreover, in the example shown in Fig. 18, the information, such as the illumination condition, is input to the control device MCU via the input device IU. However, a detector that reads the information on the reflective mask 5 may be provided. At that time, information relating to an illumination method is recorded using a bar code, for example, at a position outside a region of a circuit pattern of a reticle R. The detector reads out the information relating to this illumination condition and transmits it to the control device MCU. The control

device MCU controls the three driving systems (DR1-DR3) as described above based on the information relating to the illumination condition.

[0119]

Furthermore, in the example shown in Fig. 18, an aperture stop is provided at the position of the secondary light source formed by the reflecting type fly's eye optical system 2. However, when not requiring the illumination using an aperture stop (50c or 50d) having four eccentric apertures and performing the "annular illumination" and the "normal illumination," providing many apertures formed on the turret plate 51 are not requirements of this invention, as easily understood from the concept of this invention.

[0120]

In the light beam conversion unit 60, four eccentric light beams can be formed by structuring the reflecting surface of the first reflecting member 60a with two pairs of flat mirrors positioned facing each other and with inclination to each other and by structuring the reflecting surface of the second reflecting member 60a in a square column shape. As a result, the secondary light source formed by the reflecting type fly's eye optical system 2 can be quadrupole secondary light source eccentric from its center. Therefore, the EUV can be directed such that it is matched to the apertures for the aperture stop (50c and 50d) having four eccentric apertures.

[0121]

Next, a second example of modification of the projection exposure device shown in Fig. 17 is described with reference to Fig. 20. Members having the same functions as the members shown in Fig. 17 are referred to by the same symbols. In addition, the device shown in Fig. 20 and later described Figs. 21 and 22 is equipped with each member and system (AS1 or 51, AS2, DR1, DR2, IU and MCU) as shown in Figs. 17 and 18. However, these are omitted from Figs. 20-22.

[0122]

The difference between the above-described exposure device shown in Fig. 17 and the exposure device shown in Fig. 20 is that an auxiliary reflecting type fly's eye optical system 120 and a relay mirror 110 are positioned as an auxiliary optical integrator (auxiliary multi-light source formation optical system) and as a relay optical system, respectively, in the optical path between the reflecting mirror 15 as a collimator mirror and the reflecting type fly's eye optical system 2 as the optical integrator (multi-light source formation optical system). In view of an order of positioning from the light source side, the auxiliary reflecting type fly's eye

optical system 120 and the main reflecting type fly's eye optical system 120 can be understood as the first reflecting type fly's eye optical system (first optical integrator or first multi-light source formation optical system) and the second reflecting type fly's eye optical system (second optical integrator or second multi-light source formation optical system), respectively.

[0123]

The auxiliary reflecting type fly's eye optical system 120 shown in Fig. 20 has a first auxiliary reflecting element group 120a and a second auxiliary reflecting element group 120b.

Here, it is preferable that many reflecting elements E_{120a} structuring the first auxiliary reflecting element 120a positioned at the incident side of the auxiliary reflecting type fly's eye optical system 120 is formed in a shape similar to the entire shape (outer shape) of the first reflecting element group 20a positioned at the incident side of the main reflecting type fly's eye optical system. However, if many reflecting elements E120a structuring the first auxiliary reflecting element group 120a are structured in a shape shown in Fig. 9(a) and Fig. 14(b), it becomes difficult to position each of the reflecting elements E_{120a} densely without any spaces. Because of this, as shown in Fig. 23(a), the many reflecting elements E_{120a} structuring the first auxiliary reflecting elements 120a are respectively structured substantially in a square shape. In addition, as shown in Fig. 23(a), because the cross-section of the light beam entering the first auxiliary reflecting element group 120a becomes a substantially circular shape, the many reflecting elements E_{120a} are arranged such that the entire shape (outer shape) of the first auxiliary reflecting element group 120a becomes substantially circular. As a result, the first auxiliary reflecting element group 120a can form many light source images (secondary light sources) at the position of or near the second auxiliary reflecting element group 120a under high illumination efficiency.

[0124]

It is preferable that the entire shape (outer shape) of the second auxiliary reflecting element group 120b positioned at the exit side of the auxiliary reflecting type fly's eye optical system 120 is formed in a shape similar to the shape of each reflecting element E_{120b} structuring the second reflecting element group 20b positioned at the exit side of the main reflecting type fly's eye optical system 2, as shown in Figs. 9(b) and 14(b). Furthermore, it is preferable that each reflecting element E_{120b} structuring the second auxiliary reflecting element group 120b is in a shape similar to the shape of a light source image formed by the reflecting element E_{120a} in the first auxiliary reflecting element group 120a corresponding to the

reflecting elements E_{120b} in the second auxiliary reflecting element group 120b or in a shape such that the light source image is entirely received.

[0125]

In the example shown in Fig. 20, the main reflecting type fly's eye optical system 2 has a structure shown in Fig. 14. Because of this, the many reflecting elements E_2 structuring the second reflecting element group 20b positioned at the exit side of the main reflecting type fly's eye optical system 2 have a substantially square shape as shown in Fig. 14(b).

Therefore, because the light source image formed by each of the many reflecting elements E_{120a} structuring the first auxiliary reflecting element group 120a in the auxiliary reflecting type fly's eye optical system 120 is substantially circular, the shape of each of the reflecting elements E_{120b} of the secondary auxiliary reflecting element group 120b positioned at the exit side of the auxiliary reflecting type fly's eye optical system 120 is structured in substantially a square as shown in Fig. 23(b). Moreover, because the shape of each of the reflecting elements E_2 structuring the second reflecting element group 20b positioned at the exit side of the main reflecting type fly's eye optical system 2 is substantially square as shown in Fig. 14(b), the many reflecting elements E_{120}b are arranged such that the entire shape (outer shape) of the second auxiliary reflecting element group 120b positioned at the exit side of the auxiliary reflecting type fly's eye optical system 120 becomes substantially square, as shown in Fig. 23(b).

[0126]

Because in the example shown in Fig. 20, the first and second auxiliary reflecting element groups (120a and 120b) can be structured by the same reflecting element groups, the manufacturing cost can be reduced by common reflecting element groups.

The second reflecting element group 20b on the mask side of the main reflecting type fly's eye optical system 120, and the condenser mirror (condenser optical system) 3 shown in Fig. 20 satisfy the above-described conditional condition (2).

[0127]

Next, positioning two reflecting type fly's eye optical systems (2 and 120) is described.

By positioning the two reflecting type fly's eye optical systems (2 and 120), the number of light source images corresponding to a product of number N of reflecting elements of a reflecting element group structuring one component of the auxiliary reflecting type fly's eye optical system 120 and number M of reflecting elements of a reflecting element group

structuring one component of the main reflecting type fly's eye optical system 2 (N×M) are formed on the surface or near the second reflecting element group 20b structuring one component of the main reflecting type fly's eye optical system 2. Therefore, on the surface of or near the main reflecting element group 20b, more light source images (tertiary light sources) are formed than the light source images (secondary light sources) formed by the auxiliary reflecting type fly's eye optical system 120. Because the light from the tertiary light source from the main reflecting type fly's eye optical system 2 illuminates superimposedly in an arc shape the reflective mask 5 and the wafer, with the device shown in Fig. 20, the illumination distribution in the arc-shaped illumination region formed on the reflective mask 5 and the wafer 7 can be more uniform, and therefore, more stable exposure can be achieved.

[0128]

The relay mirror (relay optical system) 110 positioned between two reflecting type fly's eye optical systems (2 and 120) collects the light beam from the many light source images (secondary light sources) from the auxiliary reflecting type fly's eye optical system 2 and directs it to the main reflecting type fly's eye optical system 2. The relay mirror (relay optical system) 110 functions to optically conjugate a substantial surface of the light source side reflecting element group in the auxiliary reflecting type fly's eye optical system 120 and a substantial surface of the light source side reflecting element group in the main reflecting type fly's eye optical system 120. In addition, the relay mirror (relay optical system) 110 functions to optically conjugate a substantial surface of the mask side reflecting element group in the auxiliary reflecting type fly's eye optical system 120 and a substantial surface of the mask side reflecting element group in the main reflecting type fly's eye optical system 120. However, the substantial surface of the light source side reflecting element group in the auxiliary reflecting type fly's eye optical system 120 and the substantial surface of the light source side reflecting element group in the main reflecting type fly's eye optical system 120 are at a position optically conjugate with the mask 5 and the wafer as illuminated surfaces, and the substantial surface of the mask side reflecting element group in the auxiliary reflecting type fly's eye optical system 120 and the substantial surface of the mask side reflecting element group in the main reflecting type fly's eye optical system 120 are at a position optically conjugate with the position of pupil or aperture stop AS of the projection system 6.

[0129]

In the device shown in Fig. 20, when the illumination distribution in the arc-shaped illumination region formed on the reflective mask 5 and the wafer is inclined, it is preferable to move the auxiliary reflecting type fly's eye optical system 120 (move the two reflecting element groups together). That is, by making the two reflecting element groups (120a and 120b) in the main reflecting type fly's eye optical system eccentric in the X or Z direction, the inclined component of the illumination distribution can be corrected due to an act of coma that the main reflecting type fly's eye optical system 2 has, and therefore, a flat illumination distribution can be obtained.

[0130]

For instance, when the inclination of the light illuminance distribution in the left and right direction (X direction) in the arc-shaped illumination region formed on the surface of the reflective type mask 5 or the wafer surface occurs, the inclination of the light illuminance distribution can be corrected by moving the auxiliary reflecting type fly's eye optical system 120 in the X direction. When the illuminance differs at the center part and the peripheral part in the width direction (Z direction) of the arc-shaped illumination region formed on the surface of the reflective type mask 5 or the wafer surface, the inclination of the light illuminance distribution can be corrected by moving the auxiliary reflecting type fly's eye optical system 120 in the X direction.

[0131]

In order for the exposure device shown in Fig. 20 to form the image of the reflective type mask 5 on the wafer 7, it is preferable to form the image of the exit pupil of the illumination system (image of the tertiary light source formed by the second reflecting type fly's eye optical system 2) at the center of the entrance pupil of the projection system 6 in a non-aberration condition. If this condition is not satisfied, it is preferable to adjust the telecentricity of the illumination system by moving the position of the exit pupil of the illumination system, to make the adjustment with respect to the position of the entrance pupil of the projection system 6. For example, by moving the main reflecting type fly's eye optical system (two reflecting element groups 20a and 20b) 2 and the first aperture stop AS1 together, the telecentricity of the illumination system is adjusted, and therefore, the center of the entrance pupil of the projection system 6 can be matched with the center of exit pupil of the illumination system. However, if it is not necessary to provide the aperture stop AS1 at the position of the tertiary light source formed by the main reflecting type fly's eye optical

system, the two reflecting element groups (120a and 120b) in the main reflecting type fly's eye optical system 2 should be moved together.

[0132]

In the example shown in Figs. 17 and 18 as described above, to match the image of the exit pupil of the illumination system at the center of the entrance pupil of the projection system 6, the center of the exit pupil image of the illumination system can be matched with the center of the entrance pupil of the projection system 6 by moving the reflecting type fly's eye optical system (two reflecting element groups 20a and 20b) 2 and the first aperture stop AS1 together. Moreover, if it is not necessary to provide the aperture stop AS1 at the position of the secondary light source formed by the reflecting type fly's eye optical system 2 shown in Figs. 17 and 18, the two reflecting element groups (20a and 20b) in the reflecting type fly's eye optical system should be moved together.

[0133]

In the example shown in Figs. 17, 18 and 20 as described above, because the light source parts (10-15) that supply the EUV light to the reflecting type fly's eye optical system 2 require a considerable volume in actuality, it may possibly become to have a volume similar to or more than that of the main unit of the exposure device (the optical system from the reflecting type fly's eye optical system 2 to the wafer 7, and the control system). Because of this, it is possible that the light source parts (10-15) and the main unit of the exposure device may be independently separated and that the light source parts (10-15) and the main unit of the exposure device may be independently set on a board. In this case, if vibrations occur on the floor due to the walking of the operators or the like, or if a warp occurs on the floor due to the weight of the light source parts (10-15) and the main unit of the exposure device, there is a fear that the condition of adjustment may fail since the optical axis of the light source units (10-15) may be offset from the optical axis of the optical system in the main unit of the exposure device.

[0134]

Therefore, it is preferable to position a photoelectrical detector that photoelectrically detects the offset in the optical axis of the light source parts (10-15) in the optical path (optical path from the reflecting type fly's eye optical system 2 to the wafer 7) of the main unit of the exposure device and to structure the inclination of the reflecting mirror 15 as the collimator mirror adjustable. In addition, it is preferable to provide a controller that controls the inclination of the reflecting mirror 15 based on an output from the photoelectrical

detector.. As a result, the optical axis of the light source part (10-15) and the optical axis in the main unit of the exposure device can be automatically matched even if floor vibration occurs due to the operator's walking or the floor distortion occurs.

[0135]

It is difficult to obtain a high reflectivity with a mirror for soft X rays, which is obtained with a mirror for visible light. Because of this, it is preferable to reduce the number of mirrors structuring the optical system in the exposure device for soft X rays. As one method for reducing the number of mirrors, a structure of the condenser mirror 3 can be omitted by curving the second reflecting element group 10b structuring one component of the reflecting type fly's eye optical system 2 shown in Figs. 9(b) and 14(b) in the entire body. That is, by making the second reflecting element group 10b shown in Figs. 9(b) and 14(b) to have a structure in which many reflecting elements E_2 are arranged along and within a standard spherical surface (standard curved surface) having a predetermined curvature, the second reflecting element group 20b can also function as the condenser mirror 3. Fig. 21 shows the second reflecting element group 20c, which is the second reflecting element group 20b structuring one component of the reflecting type fly's eye optical system 2 shown in Figs. 8, 17 and 18 having also a function of the condenser mirror 3. By changing the structure of the second reflecting element group 20b on the mask side of the main reflecting type fly's eye optical system 2 shown in Fig. 20 to the one shown in Fig. 21, it is also possible to make the second reflecting element group 20b shown in Fig. 20 to have the function of the condenser mirror 3. The projection system 6 shown in Fig. 21 is structured from 6 pieces of mirrors (6a-6f) to make the image forming performance even better.

[0136]

The examples shown in Figs. 17, 18, 20 and 21 show an exposure device using a laser plasma light source. However, a disadvantage of the laser plasma light source is that it generates a spray of minute particles or debris. If the optical parts are contaminated by this minute spray, the performance of the optical system (reflectivity of the mirror and uniformity of the reflection) is deteriorated. Because of this, it is preferable to position a filter that permeates the soft X rays but not the dispersed particles, between the light source and the main unit of the exposure device. A thin film of a light transmitting element such as a membrane can be used as a filter.

[0137]

Fig. 22 shows an example in which the filter 16 for preventing debris is provided to the exposure device shown in Figs. 17, 18, 20 and 21.

As shown in Fig. 22, by providing the debris preventing filter 16 between the elliptical mirror 14 and the collimator mirror 15, even if contamination due to the debris occurs, the elliptical mirror 14 and the filter 16 should just be replaced with new ones, thereby reducing the operating cost.

[0138]

As described above, because permeability of the soft X ray is weak in the air, the exposure device shown in Figs. 17, 18, 20 and 21 are enclosed by the vacuum chamber 100. However, it is difficult for the heat accumulated in the optical parts to escape, and therefore, the mirror surfaces can be easily warped. Thus, it is preferable to provide a cooling mechanism to each of the optical members in the vacuum chamber 100. It is more preferable that a plurality of cooling mechanisms is provided to each of the mirrors. If the temperature distribution in the mirrors can be controlled, the warping of the mirror at the time of exposure operation can be better controlled.

[0139]

Furthermore, a multi-layer film is provided on a reflection surface of each mirror structuring the optical system in the exposure device shown in Figs. 17, 18, 20 and 21. It is preferable that this multi-layer film is formed by laminating a plurality of materials from molybden, ruthenium, rhodium, silicon and silicon oxide.

[0140]

[Effects of the Invention]

As described above, according to this invention, by maintaining a numerical aperture of illumination light to be substantially constant, an illuminated surface can be uniformly effectively illuminated in an arc shape.

[Brief Description of the Drawings]

Fig. 1 is a schematic structural view of an exposure apparatus related to a first embodiment according to this invention.

Fig. 2 is a front view showing a structure of a reflecting element group 2 shown in Fig. 1.

Fig. 3(a) is a front view showing each reflecting element in the reflecting element group 2 shown in Fig. 2. Fig. 3(b) is a cross-sectional view showing a cross-sectional state of the reflecting element shown in Fig. 3(b).

Fig. 4 is a diagram showing an arc-shaped illumination region IF formed on a reflecting type mask 5.

Fig. 5 is a diagram showing an operation of the reflecting element group 2 shown in Fig. 1.

Fig. 6(a) is a cross-sectional view showing a cross-sectional shape of a reflecting element when each reflecting element in the reflecting element group 2 is aspherical. Fig. 6(b) is a front view of the reflecting element shown in Fig. 6(a).

Fig. 7 is a cross-sectional view showing a cross-sectional shape of a condenser mirror when the condenser mirror is aspherical.

Fig. 8 is a view showing a schematic structure of an exposure apparatus related to a second embodiment according to this invention.

Fig. 9(a) is a front view showing a structure of a first reflecting group 20a. Fig. 9(b) is a front view showing a structure of a second reflecting element group 20b.

Fig. 10(a) is a front view showing each reflecting element in the first reflecting element group 20a shown in Fig. 9(a). Fig. 10(b) is a cross-sectional view showing a cross section of the reflecting element shown in Fig. 10(a).

Fig. 11(a) is a front view showing each reflecting element in the second reflecting element group 20b shown in Fig. 9(b). Fig. 11(b) is a cross-sectional view showing a cross section of the reflecting element shown in Fig. 11(a).

Fig. 12 is a diagram showing an operation (or action) of the first and second reflecting element groups shown in Fig. 8.

Fig. 13 is a diagram showing a modified example of an exposure apparatus related to a second embodiment shown in Fig. 8.

Fig. 14(a) is a front view showing a modified example of the first reflecting element group 20a shown in Fig. 9(a). Fig. 14(b) is a front view showing a modified example of the second reflecting element group 20b of Fig. 9(b).

Fig. 15 is a diagram showing an operation (or action) of the first and second reflecting element groups (20a, 20b) shown in Fig. 14.

Figs. 16(a), (b), and (c) are diagrams showing a structure of a conventional illumination device.

Fig. 17 is a diagram showing an example of modification of the exposure device according to the first embodiment shown in Fig. 1.

Fig. 18 is a diagram showing the first example of modification of the exposure device shown in Fig. 17.

Fig. 19 is a perspective view showing a structure of the turret plate 51 shown in Fig. 18.

Fig. 20 is a diagram showing the second example of modification of the exposure device shown in Fig. 17.

Fig. 21 is a diagram showing the third example of modification of the exposure device shown in Fig. 17.

Fig. 22 is a diagram showing the fourth example of modification of the exposure device shown in Fig. 17.

Fig. 23(a) is a front view showing a structure of the first auxiliary reflecting element group 20a shown in Fig. 20(a). Fig. 23(b) is a front view of the second auxiliary reflecting element group 20b shown in Fig. 20(b).

[Explanation of the Symbols]

1 Light source device

2, 20a, 20b Reflecting element groups

3 Condenser optical system

4 Deflecting mirror

5 Reflecting type mask

6 Projection system

7 Wafer

[Document] Abstract

[Abstract]

[Object]

To provide an illumination device, having illumination effectiveness much better than a conventional device, which can provide high throughput as well, an exposure apparatus, and a method of fabricating a semiconductor device using the exposure apparatus.

[Structure]

This invention is constituted by a light source means which provides a light beam, a multi-light source formation optical system which forms many light sources based on a light beam from the light source means, and a condenser optical system which illuminates an illuminated surface by converging light beams from the many light sources formed by the multi-light source formation optical system. The multi-light source formation optical system has a first optical element group including many first optical elements, and the many first optical elements respectively have a first optical surface having an arc-shaped contour in order to form many light sources by dividing a wavefront of the light beams from the light source means into many arc-shaped light beams.

[Selected Figure] Fig. 1